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सुरंगों के लिए भूवैज्ञानिक अन्वेषण — दिशानिर्देश

Geological Exploration for Tunnels — Guidelines

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Geological Investigation and Subsurface Exploration Sectional Committee, WRD 05

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Geological Investigation and Subsurface Exploration Sectional Committee had been approved by the Water Resources Division Council.

Tunnels have been an intrinsic part of infrastructure and energy development scenario in the country and their significance is increasing day by day. Many hydro-power, irrigation and other water resources projects have experienced construction problems due to tunneling challenges especially where long tunnels were involved. Similarly, a number of railway and highway tunnels are under excavation where moderate to severe construction difficulties are being reported. A number of new tunneling projects in the country in communication sectors, such as highways and railways in the mountains and lift irrigation schemes particularly in peninsular India are being executed or are in the planning stage.

Selection of proper site and fixing of tunnel alignments and advance knowledge of tunneling media are mandatory requirements for any tunneling projects. To undertake systematic investigation and testing for tunnels and deliver a reliable geologic evaluation it has been felt necessary to have guidelines for geological investigations which encompasses geological, geophysical, soil and rock mechanics investigations so that a consistent and systemic approach can be applied. It is also important to understand that various methodologies, such as conventional drill and blast, and machine tunneling by TBMs and road headers are in vogue. These standard covers investigation and testing required for conventional drill and blast as well as for machine based tunnel boring or excavation by road headers.

The standard has been framed to cover guidelines for development of detailed report after the conclusion of investigations so that the investigation data is available for engineers in proper format where geological findings can be translated to engineering requirement. Such investigations should be able to deliver a reliable geological evaluation for preparation of geotechnical baseline report (GBR) also. The standard also aims to identify the rock types and their engineering significance for stability of tunnels, ground water conditions, minimizing geological surprises and unforeseen hazards in tunnels, project cost and time overrun etc.

The composition of the committee responsible for the formulation of this standard is given at Annex D.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

GEOLOGICAL EXPLORATION FOR TUNNELS — GUIDELINES

1 SCOPE

This standard gives specific guidelines for geological investigation as required for fixing of tunnel alignments, to evaluate geologic conditions along the tunnel route, requirement of geotechnical analysis and proposals for rock support and treatment of weak zones. It also covers both surface and sub-surface investigations to be carried out in different stages of investigations.

2 REFERENCES

The standards listed contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 GENERAL

It may be noted that at all the stages a geological report is to be submitted along with engineering geological appraisal based on studies, investigations and testing carried out. Similarly, the geological maps and sections are also an outcome of the investigations carried out and are invariably a part of the report. Monitoring of health of the tunnel is necessary for long term stability of tunnel and as such recording and preservation of geological data is necessary.

4 STAGES OF GEOLOGICAL INVESTIGATIONS

Geological investigations for tunnels are normally carried out in four stages, as stated below:

a) Reconnaissance or pre-feasibility stage — PFR stage,

b) Preliminary investigation or feasibility stage — FR Stage,

c) Detailed investigation or detailed project report — DPR Stage, and

d) Construction stage.

5 RECONNAISSANCE INVESTIGATIONS OR PRE-FEASIBILITY STAGE (PFR STAGE)

In the reconnaissance stage the preliminary tunnel alignment is formulated or devised or conceived based on topographic geologic and engineering considerations. Reconnaissance stage investigations are of preliminary nature during which the tunnel alignment, its length, broad geological features are observed. Before the site visit, literature pertaining to regional geology should be reviewed. During this study, the available topographical map (Survey of India topo sheets 1 : 50 000/1 : 25 000) and published geological maps are used to study the topography, geomorphology, broad geology and tectonics of the area, examine the approach and accessibility of the project area and tentatively locate the tunnel. The overall condition of the inlet and outlet of the tunnel are also examined. Alternative tunnel alignments may also be proposed for evaluation and selection of the preferred alignment.

6 PRELIMINARY INVESTIGATIONS OR FEASIBILITY STAGE (FR STAGE)

During feasibility stage of investigations, the activities should be undertaken on 1 : 10 000/1 : 5 000 scale with contour interval of 5 m to 2 m around the project area involving surface geological mapping followed by subsurface explorations. The objective is to finalize the tunnel alignment on the basis of surface investigations and precisely determine the subsurface geological features, such as rock types, structural features such as folds, faults etc. and other engineering properties of the rock types. The locations of the tunneling problems are identified and attendant problems are identified with solutions for the guidance of the engineers. The investigations/explorations are taken to the stage at which the tunnel alignment is decided. As mentioned above, surface geological mapping along all the proposed alternative alignments may be carried out in 1 : 10 000/1 : 5 000 scale on site specific survey sheets before finalizing the best feasible layout based on topographical, geological, hydrological and design considerations. Geological section along the tunnel should also be prepared.

The emphasis is on site specific geological mapping, remote sensing followed by geophysical investigation as applicable. In this stage the data generated should enable finalization of tunnel alignment and preparation for design inputs to estimate preliminary cost.

7 DETAILED INVESTIGATION STAGE (DPR STAGE)

The investigations carried out under this stage are primarily aimed at guiding the engineers for further optimization of tunnel alignment if required and assess the quantities of tunnel supports, rock mass strengthening, lining and grouting needs. Investigations may be further aimed to minimize geological uncertainties in the tunnel alignment for assessing the remedial measures. Rock properties shall be determined through in-situ test and/or laboratory test for deciding the requirement of tunnel support, lining and grouting. Sometimes, the data collected during this stage are found to be useful in resolving certain construction/post construction stage problems.

8 CONSTRUCTION STAGE

Geological investigations and recording of data are of paramount importance in construction stage also. For exploration of unknown areas or identified problematic area ahead of tunnel face, activities, such as probe drilling, core drilling, tunnel seismic prediction, suitable geo-electrical survey or other geophysical investigations and instrumentation methods data are used. Depending on site condition the most appropriate technique(s) or a combination of techniques mentioned above are to be employed. However, critical reaches should be explored by confirmatory high-quality core drilling.

3D geological mapping of tunnel along with rock mass classifications, development of sections, localized projections and any other test results form a very important part of documentation during the construction stage and are guiding cornerstones for rock support and treatment methods. In the post construction stage also and after the lining, these records may be utilized for repairs or further necessary treatment.

9 METHODS OF INVESTIGATION

9.1 Reconnaissance or Pre-feasibility Stage (PFR Stage) Investigation

Reconnaissance stage investigation is of very preliminary nature and it begins with initial study of the engineering proposal followed by geologic literature reviews from existing reports, maps, sections particularly for regional geology and tectonic setup. Subsequently site visit(s) is/are undertaken and this field visit(s) should be done by a small team of two to three members drawn from the disciplines of geology, engineering and hydrology (or a transport engineer). Before the field visit, the team members are required to collect secondary data namely, geological map(s) on 1 : 50 000/1 : 25 000 scale or as available, engineering details, such as location; approach and accessibility; proposed use of the tunnel and quantity of discharge, proposed to be passed through the tunnel (in water resources projects) or the dimensions of the transport vehicles or locomotives etc. proposed to pass through the tunnel (in transportation projects).

The geological maps required for preliminary study are normally available from the Geological Survey of India (GSI) or state directorate of geology and mining. Where required maps are not available from Geological Survey of India or state bodies, Engineer In-charge may decide to use other reputed resources.

Depending on availability of satellite imageries, a preliminary study of the terrain, geomorphology and geology is to be undertaken. In case satellite imageries are not readily available, the literature reports as available may be referred along with selective traverses in the area.

During this stage, the rock types and preliminary data about joints, fractures and shears *vis-à-vis* tunnel alignment are identified and collected. The inlet and outlet portals of the proposed tunnel are located as per project requirement. The requirements for dimensions of the tunnel based on the volume of water to be discharged or volume of traffic to pass through are also assessed.

NOTES

1 In case of variation between recommended scales in this standard and referred standards, the scales suggested in this standard shall be followed.

2 During all stages, topographic surveys and geological mapping shall be followed in accordance with IS 5497 and IS 15686 respectively.

9.1.1 *Report Preparation*

The Pre-feasibility/reconnaissance report should include:

a) Description of regional geology and main tectonic features around project area;
b) Geological map of tunnel alignment as the case may be showing major litho units, faults and thrusts, major overburden areas, landslides and broad geo-hydrological features;
c) Description and preliminary engineering assessment of rock types expected in the tunnel;
d) Major problems, difficulties foreseen in the alignment; and
e) Alternative alignment and recommendations.

9.2 Preliminary Investigation or Feasibility Stage (FR) Stage Investigations

9.2.1 *Planning and Survey*

An elaborate planning is needed to conduct geological investigations for a tunnel proposed for construction. The sequence of planning requirement may be as given below:

a) Based on review of literature, regional geological map, PFR report, remote sensing studies the area required for site specific topographic survey should be demarcated. The area to be covered by the above survey should cater to the requirement of alternative studies for tunnel alignment and development of geological model;

b) Large scale contour plan on 1 : 10 000/1 : 5 000 scale with 5 meter or 2 meter contour interval is to be prepared either through Survey of India or survey using latest equipments like DGPS, total station, LIDAR technique and/or digital elevation modeling with ground checks; and

c) In case of contrary observations or interpretations in regional geology and tectonics, the reports or maps from Geological Survey of India will have precedence over others.

9.2.2 *Remote Sensing Studies*

Depending on availability of satellite imageries a study of the terrain, geomorphology and geology is to be undertaken. Further a broad tectonic map of the area may also be prepared. This will be of greater use in inaccessible areas over the tunnel alignment.

9.2.3 *Geological Mapping*

Geological mapping is carried out on survey sheets prepared on 1 : 10 000/1 : 5 000 scale along with use of survey instruments or by GPS methodology. It is recommended that 1 : 5 000 scale with 2 m contour interval may be used in compact layouts with smaller length of tunnels. However, for longer tunnels 1 : 10 000 scale with 5 m contour interval may to be used. It is imperative that sufficient area is covered by geological mapping right across the tunnel alignment so that alternative alignments can be evaluated and construction adits or parallel tunnel if any can also be planned. And for this purpose, area right down to river bank or lower elevations below the tunnel level in an otherwise situation where river is not present may be covered, if necessary. Strip geological mapping with a defined coverage say 200 m on either side may be avoided as it has been found that the same is not sufficient to make geological interpretations on many occasions.

In the geological mapping for tunnels, areas of overburden and bed rock are demarcated. Further classification of overburden is also to be carried out which is a good indicator of depth to bed rock. In the out crops it is preferable to assign identification numbers and note their discontinuity characteristics. A performa for collecting discontinuity and rock mass data is given in Annex B. Where further details of discontinuity are to be recorded, IS 11315 (Part 1 to 10) may be referred.

After surface geological mapping an outcrop map should be developed. This need to be read with the outcrop parameters collected on the performa. The following geological information/data is to be made available on the outcrop map:

a) Occurrence of overburden, outcrops and disposition of various rock types. Vital rock mass parameters, such as rock strength, volumetric count of joints, degree of weathering, geological structure, block description etc. and indications of neo-tectonics activity if any.

b) Plotting of structural features, namely, bedding/foliation and joints. Complete discontinuity survey is required to be carried out for each rock outcrop and for every joint set including orientation (strike and dip), spacing, aperture, type of filling etc.

c) Water springs and other evidences of water table are recorded.

After the outcrop map is prepared and data is collected, interpreted geological map is to be developed which is expected to contain the following:

a) Occurrence of various rock types in the mapped area including interpreted contacts,

b) Rock structural elements, namely, folds, faults, joints, shears, and

c) Tectonic elements, namely, thrusts, shear zones, neo-tectonic evidences, etc.

In the interpreted map over burden including foliage etc. is removed and underlying geological formation/rock types are depicted as they will appear below the covered areas.

9.2.4 *Sub Surface Investigations*

9.2.4.1 *Geophysical investigation*

It is suggested that airborne time domain electromagnetic survey may be carried out in inaccessible terrain for ascertaining broad subsurface features for the entire tunnel length. The data thus generated needs to be correlated with results from surface and interpreted geological maps. Other methods such as seismic refraction survey, resistivity profiling/sounding or imaging, gravimetric surveys, ground penetrating radar (GPR) technique as applicable may be used for exploration at this stage. For guidance in seismic refraction and electrical resistivity methods IS 15681 and IS 15736 may be referred.

9.2.4.2 If necessary, the low cover zones under which the tunnel is to planned may be probed by shallow drill holes to estimate depth to bed rock. Necessary to be used/adopted for core drilling, presenting information and storage of core boxes have been given in **9.3.3.1** under core drilling as well as in Annex C.

9.2.5 *Rock Tests*

The following geological data are utilized to prepare a geological section along the proposed tunnel alignment which gives a tentative picture of the subsurface geological conditions. The geological map and the developed geological section form the basis for detailed subsurface geological investigation for gathering minute geological and geotechnical details required for tunnel excavation, designing of supports, lining and dewatering arrangements:

a) Representative rock samples from various lithologies are to be collected for petrographic studies for proper nomenclature of mappable units, and

b) Basic rock mechanic tests on representative samples from different lithologies like uniaxial compressive strength, point load index are recommended.

9.2.6 *Report Preparation*

The feasibility/preliminary investigation stage report should adhere to following requirements:

a) Description of regional geology and main tectonic features around project area;
b) Geological map of tunnel alignment on 1 : 10 000 scale showing major litho units, faults and thrusts, major overburden areas, landslides and broad geo-hydrological features;
c) Presentation of maps and drill hole logs in approved formats in geophysical reports as applicable;
d) Geological section along the tunnel;
e) Description and preliminary engineering assessment of rock types expected in the tunnel after integration of all the data generated;
f) Major risks, difficulties foreseen in the tunnel to be mentioned; and
g) Recommendations.

9.3 Detailed Investigations or Detailed Project Report (DPR) Stage

9.3.1 *Updating of Outcrop and Interpreted Geological Map*

During the feasibility, stage outcrop and interpreted maps are developed on 1 : 10 000/1 : 5 000 scale after the earlier geological mapping campaign. In case new outcrops or exposures from foot paths etc. are visible with improved accessibility, the same may be mapped and geological plans and section be updated.

Critical reaches (lithological contacts, low cover zones, *nallah* crossings, and probable fault/shear zones) may be seen and reviewed again. Areas surrounding adit portals may be mapped at 1 : 500/1 : 200 scale, 3-D geological logging of drifts (at portals) may be carried out in 1 : 50/1 : 100 scale and geological logging of drill holes to be carried out in 1 : 100 scale. The scales given in IS 4464 and IS 15686 be referred at extant.

Reasonable geological projection is a prerequisite for development of a realistic sub-surface geological model along tunnel alignment. An interpreted geological map combining surface geological mapping, remote sensing, geophysical survey, drilling/drifting etc. should be prepared during DPR stage along with sub surface geological model along tunnel alignment. Accordingly, outcrop and interpreted maps should be updated during the DPR stage. In critical low cover reaches, such as *nallah* intersections or important geological contacts etc., observed survey sections (1 : 2 000 scale or larger) need to be developed for adequacy of cover and safety of the tunnel. The details should be supplemented with core drilling.

9.3.2 *Geophysical Methods*

In remaining areas other than conducted in *FR* stage or in case the alignment has been modified, seismic refraction, electrical resistivity imaging, *GPR* methods etc. may be used. These investigations should precede exploratory drilling and drifting activities. However, it should be aimed to complete all geophysical surveys in *FR* stage only.

9.3.3 *Sub Surface Investigations*

9.3.3.1 *Core drilling*

Drilling is planned judiciously along the tunnel alignment at locations where there is less cover over the tunnel grade or where certain adverse geological features are suspected. As mentioned in **9.2.4** it is expected that low cover reaches along the tunnel alignment have been investigated by shallow drill holes. If drilling has not been carried out in FR stage, , it shall be done during the DPR stage. However, in case there is a modification in the tunnel alignment due to geological, design or engineering considerations further exploration by drilling should be carried out.

To augment geological logging, bore hole geophysical logging may be done particularly when core recovery is poor. Depending on the site conditions and whether the hole is uncased or cased, one or more of the following methods may be useful:

a) Bore hole camera/optical methods,
b) Electrical methods,
c) Sonic/acoustic methods, and
d) Natural gamma logging.

Drilling is also carried out slightly inward from the portal locations to decipher the geological conditions of the portal locations. Suitable drill holes are to be placed for confirmation of geological contacts, weak zones, fracture/shear zones, water table etc. It is not always necessary that the depth of the hole may be down to invert of tunnel grade. Appropriate depth to delineate inclination of beds or contacts may be decided on the basis of sections prepared. Notwithstanding the above, a minimal of at least one drill hole per kilometer irrespective of the depth based on geological considerations is considered a necessary input during the DPR stage investigations.

In case any area remains unknown even after conventional investigations and which may be detrimental to smooth completion of project, directional core drilling should be undertaken to cover such areas.

Appropriate drilling rigs with necessary accessories and experienced crew are to be deployed for drilling. The drilling operation should be properly monitored and for drilling methodology guidance from IS 6926 may be followed. The location of holes, depths, types of casing, core barrel, etc. are decided as per the site condition and geology. Driller should try to regulate the speed of drilling so that cores do not get broken, use double or triple tube core barrels fitted with core lifter for obtaining maximum core recovery. Daily drilling report should be submitted for regular review in the standard proforma for the purpose of giving instructions regarding change in the operational procedure, stopping the hole, etc. For guidance in drilling and recording of data IS 5313 and IS 4464 may be referred.

The cores, including the sludge samples, are to be kept in the standard core boxes (*see* IS 4078). The core boxes shall be numbered run segregated and lengths marked and each box shall be photographed. Lengths of the individual cores should also be marked. The core boxes are presented for geological logging in the format as referred in IS 4464. After the geological logging, the core boxes should be stored at a suitable place as directed by the Engineer In-charge. Water pressure testing should also be conducted in all the bore holes. [*refer* IS 5529 (Part 1) and IS 5529 (Part 2)].

NOTE — It may practically be not possible always to carry out exploratory drilling after every one km interval along tunnel en-route due to various constraints, however efforts should be made to optimize drilling in a way to obtain maximum geological information as per site suitability and keeping in view logistics, time and economics.

9.3.3.2 *Drifting*

Drifts are of standard size 1.8 × 2.2 m and may extend to a depth of 30 to 50 m from the portal face in bed rock or to a required location.

The drifts provide direct access to examine and study the rock formation, its quality, presence of discontinuities and their dimensions, etc. The drifts also facilitate carrying out of some *in situ* tests, such as, closure measurements, deformability modulus, shear test, in situ stress condition, etc. The 3-D geological log on 1 : 50 scale should be prepared marking orientation, thickness of rock units, the shear seams/zones and their thickness, joint pattern. Based on actually observed geological data, the Rock Mass Rating (RMR) and Rock Mass Quality (Q) and Geological Strength Index (GSI) should be assessed to decide the requirements of rock bolting, grouting, tunnel supports and dewatering arrangements.

9.3.4 *Rock Mechanic Tests*

9.3.4.1 *Laboratory tests*

The rock cores as well as lump/block samples obtained from drilling and surface geological mapping and rock samples obtained from drifting are subjected to laboratory testing for determination of physico-mechanical properties, namely, specific gravity, modulus of elasticity, Poisson’s ratio, unconfined compressive strength, tensile and shear strength, swelling index (for joint infillings), slake durability, etc. For the purpose of reference, specialized tests for TBM includes brittleness index, Sievers-J value, drilling rate index, Cerchar abrasivity index, uniaxial compressive strength, tensile strength, modulus of elasticity and poisons ratio. A list of tests to be conducted is given in Annex C.

9.3.4.2 *In-situ tests*

In situ tests are normally carried out to understand the rock mass behavior which includes:

a) Deformation characteristics; and
b) In-situ rock stress measurements, where required.

Generally, in-situ tests are carried out inside the drifts if constructed along the intake, at the proposed adit locations etc. In case substantial length of adit or tunnel is expected in overburden, proper geotechnical testing such as gradation analysis, permeability, basic and index properties of overburden material, shear strength parameters should be determined.

9.3.5 *Modeling and Rock Mass Classification*

The data generated during surface and subsurface investigations needs to be analyzed so as to evaluate the rock-mass behavior during tunneling. These data can be systemized for preparing geological model of the tunnel. Modern tools like 2D/3D geological modeling are available and these should be used to predict the geological behavior of rock mass over critical stretches. The results may lead to better engineering judgments in optimizing the tunnel support requirements.

9.3.5.1 *Rock mass classification*

Characterization of rock mass may be carried out using widely applicable/acceptable classification systems like RMR, Q and GSI (geological strength index) rock mass characterization for tunnels using above systems should be carried out judiciously and it would be appropriate to use more than one method simultaneously and compare the outcomes before finalizing the rock classes and corresponding support systems [*see* IS 13365 (Part 1), IS 13365 (Part 2), IS 13365 (Part 3) and IS 13365 (Part 4)].

9.3.6 *Geo-hydrological Studies*

Geo-hydrological studies of the tunnel area, establishing groundwater table, natural springs/geothermal springs and their elevation are undertaken so as to postulate the likely groundwater problems and suggesting remedial measures, such as, grouting of the tunnel walls and the crown areas, providing drainage holes and dewatering arrangements during and after the tunnel excavation.

Geohydrological condition along the tunnel may be determined using drilling/water pressure testing, geophysical survey and installing piezometers inside the drill holes wherever required. Study of nearby springs, *nallahs* etc. can also provide good ideas about the geo hydrological conditions. Guidelines are also available in IS 14330. Monitoring of water levels in all the completed holes is necessary (*refer* IS 6935).

9.3.7 *Kinematic Analysis*

Kinematic analysis using geotechnical software may be carried out for stability analysis of potential wedges using the average discontinuity data collected during geological mapping/scan line survey. The analysis results may be used for finalizing suitable support system.

9.3.8 *Report*

Detailed investigation stage report should adhere to following minimal requirements:

a) Description of regional geology and main tectonic features around project area;

b) Geological map of tunnel alignment on 1 : 5 000 or 1 : 10 000 scale as the case may be showing major litho units, faults and thrusts, major overburden areas, landslides and broad geohydrological features;

c) Geological section along the tunnel and adits as required on suitable scale (1 : 2 000 for adits to 1 : 5 000/1 : 10 000 for main tunnel);

d) Geological map of portals on 1 : 200/1 : 500 scale;

e) Geophysical reports;

f) Presentation of maps and drill hole logs in approved format;

g) Results and reports of rock mechanic or soil tests if any;

h) Description and preliminary engineering assessment of rock types expected in the tunnel and tentative percentages of rock types and rock classes expected;

j) Major problems, difficulties foreseen in the alignment;

k) In case of tunneling through overburden, the same may be specially mentioned along with solutions;

m) Solutions for negotiating difficult zones and precautions to be undertaken;

n) Overall geotechnical evaluation based on geological, geophysical, rock mechanics and classification data;

p) For TBM Tunnels specialized evaluation is required regarding rock strength, joint spacing blockiness or otherwise, shear zones, cutter specifications, probing mechanisms, support methodology, treatment of water ingress and finally lining methodology; and

q) Recommendations.

NOTE — DPR is a comprehensive document that covers entire geological and geotechnical data followed by their interpretations and outcome of these interpretation are the input parameters for design and contract framing. Accordingly depending upon the requirement of the owner the data presented in the DPR may be utilized to prepare Geological Factual Report (GFR), Geological Interpreted Report (GIR) and Geological Baseline Report (GBR) as the case may be. Any subsequent confirmation test results may be suitably added to the document.

9.4 Construction Stage Investigations

The methods for construction stage investigations are generally of routine nature and same as done during previous stage of investigation. Certain methodology of blast pattern and blasting most suitable to the tunneling media may also be evolved and followed. Besides, the following activities continue as routine works:

a) Take photograph of tunnel face after each blast during the geological mapping;

b) 3-D geological mapping of progressive tunnel excavation;

c) Recording of groundwater seepage along with mapping;

d) Reassessing the rock mass behavior, carrying necessary design corrections;

e) To facilitate changes in tunnel supports if required;

f) Adopting most suitable tunneling method based on rock type and nature of rock structures;

g) Keeping the 3-D tunnel logging record on 1 : 100 or 1 : 200 scale for future reference.

h) Correlate likelihood of any problem during tunneling as envisaged during investigation stage with actual encountered condition and if required should propose additional support/restoration measures (pre-grouting, fore poling, pipe roofing etc.) and mid-course design corrections;

j) The data obtained during construction can be subjected to numerical modelling on suitable computer program for precise understanding of rock mass behavior; and

k) Rock mass behavior in the tunnel is monitored by installing the instruments on regular basis.

9.4.1 *Ahead of Face Investigation*

There should be provision of deep probe holes and core drill holes from tunnel face to explore the geology ahead of the tunnel face. These holes are required while tunneling through highly varying weak and fragile geology, such as in the Himalayas. The probe holes drilling should be taken with extreme precautions. Probe should be done preferably in entire stretch of the tunnel and necessarily in critical reaches identified in the contract documents. Probe holes means percussion drilling in which core is not recovered. However, a record of penetration rate in mm/min, colour and quantity of return water and identification of crushed rock chips if any, should be maintained along with machine details. Core drill holes means drilling with core recovery and logging and such drill holes are proposed to delineate weak zones, fracture zones or shear zones ahead of tunnel face. Whenever required, special face investigation technique like TSP and Beam may be used ahead.

9.4.2 *Mapping and Rock Classification*

3D geological logging of the tunnel on approved formats along with rock mass classification should be carried out to maintain records and also advice for rock support. These logs are also used to verify the results from investigation as mentioned in **9.4.1**.

In the case of tunnels driven by shielded TBMs where rock mass is not exposed for mapping the machine should have provisions for advance core drilling in addition to geophysical methods, such as TSP/geoelectrical scanning technology to generate geological data. Whereas probe drilling (percussion/non-coring) needs to be carried out continuously, core drilling should be done on the basis of site recommendation or any other special design requirement.

Alternatively, the record from the machine such as RPM and rate of penetration should be maintained and correlated with geological formations and hardness of rock.

9.4.3 *Instrumentation*

Instrumentation is the activity which is undertaken concurrently with tunnel excavation. The objective of instrumentation is to know precise rock mass behavior affecting the tunnel stability and support competence. The following instruments are generally installed to monitor the rock mass behavior affecting tunnel stability:

a) Closure pegs are fixed on the tunnel wall to record periodic closure in the tunnel wall and roof,
b) Multipoint borehole extensometers to assess the extent of broken zone around tunnel opening,
c) Load cells on supports to measure rock loads being transferred by the rock to the installed supports,
d) Pressure cells between the supports and tunnel wall rocks,
e) Piezometers may be required to monitor the seepage pressure, and
f) Optical targets for monitoring of tunnel convergence.

The frequency of instruments, such as tape extensometers in the tunnel should be based on geological and rock conditions. It may be required at closer spacing of say 5/10 m and sometimes even at an interval of 100 m to 500 m depending on rock mass condition and behavior. Readings of instrumentation results needs to be thoroughly observed and correlated with geological conditions for effective utilization/decision making.

9.4.5 *Documentation*

It is necessary to record and preserve 3D geological logs, classification data, results of probe holes and other tests carried out during construction stage also. Details of grouting and instrumentation data generated are also required to be recorded. Periodically, a geotechnical memo (preferably once a month or quarter) may be brought out giving details of such activities and records. The frequency may be reduced as per requirement of design office or while dealing with problems. At the end of the project a comprehensive document regarding the geological and geotechnical conditions in the tunnel along with remedial measured adopted and supports provided is to be prepared.

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
4078 : 1980	Code of practice for indexing and storage of drill cores (*first revision*)
4464 : 2020	Code of practice for presentation of drilling information and core description in foundation investigation (*second revision*)
5313 : 2020	Guide for core drilling observations (*second revision*)
5497 : 2008	Guide to topographical surveys for river valley projects (*second revision*)
5529 (Part 1) : 2013	Code of practice for in-situ permeability test: Part 1 Test in overburden
5529 (Part 2) : 2006	In-situ permeability tests: Part 2 Tests in bedrock (*second revision*)
6926 : 1996	Diamond core drilling — Site investigation for river valley projects — Code of practice (*first revision*)
6935 : 1973	Method for determination of water level in a bore hole
11315 (Part 1) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 1 Orientation
11315 (Part 2) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 2 Spacing
11315 (Part 3) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 3 Persistence
11315 (Part 4) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 4 Roughness
11315 (Part 5) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 5 Wall strength
11315 (Part 6) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 6 Aperture
11315 (Part 7) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 7 Filling
11315 (Part 8) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 8 Seepage
11315 (Part 9) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 9 No. of sets
11315 (Part 10) : 1987	Method for the quantitative description of discontinuities in rock masses: Part 10 Block size
13365 (Part 1) : 1998	Quantitative classification system of rock mass — Guidelines: Part 1 RMR for predicting of engineering Properties
13365 (Part 2) : 2019	Quantitative classification systems of rock mass — Guidelines: Part 2 Rock mass quality for prediction of support pressure, support system and engineering properties in underground openings (*first revision*)
13365 (Part 3) : 1997	Quantitative classification system of rock mass —Guidelines: Part 3 Determination of slope mass rating
13365 (Part 4) : 2014	Quantitative classification system of rock mass — Guidelines: Part 4 Geological strength index (GSI)
14330 : 1996	Groundwater investigations for hydraulic structures — Guidelines
15681 : 2006	Geological exploration by geophysical method (seismic refraction) — Code of practice
15686 : 2006	Recommendations for preparation of geological and geotechnical maps
15736 : 2007	Geological exploration by geophysical method (electrical resistivity) — Code of practice

ANNEX B

(*Clause* 9.2.3)

PERFORMA FOR COLLECTING DISCONTINUITY AND ROCK MASS DATA FOR TUNNELING

Project:							
Location/Structure:							
Outcrop No.							
Joint Set No.							
Type of joint							
Dip amount							
Dip direction							
Joint description	Length/direction						
	Type of termination						
	Persistence (m)						
	Spacing (m)						
	Aperture (mm)						
	Roughness						
	Alteration						
	Type of filling						
Rock mass description	Rock type						
	Strength						
	No. of joint sets						
	Degree of weathering						
	Geological structure						
	SRF						
	Water seepage						
	Block description						
	Block size	Block dimension					
		No. of joints/m^3					
Remarks							
Date	Engineer Incharge						

ANNEX C

(*Clauses* 9.2.4.2 *and* 9.3.4.1)

GEO-PARAMETERS RELATED TO TUNNELING

Parameter	Location	Feasibility Stage	DPR Stage	Construction Stage
(1)	(2)	(3)	(4)	(5)
Physical Properties of Rock				
Density test	Lab	A	N	A
Water absorption test	Lab	A	N	A
Porosity test	Lab	A	N	A
Mineralogical and petrographic analysis	Lab	—	N	—
P and S waves velocity	Site	A	N	A
Hardness	Lab	A	N	—
Slake durability test	Lab	—	N	N
Mechanical Properties of Intact Rock				
Uniaxial compressive strength	Lab/Site	N	N	A
Elastic constants under uniaxial stress conditions	Lab/Site	—	N	A
Tensile strength	Lab/Site	A	N	A
Shear strength	Lab/Site	N	N	A
Point load strength index	Lab/Site	—	N	A
Hoek – brown constant	Lab	—	N	—
Rock Joint Properties				
Joint shear strength	Lab	A	N	N
Joint roughness coefficient	Lab	A	N	N
Joint wall compressive strength	Lab	A	N	N
Basic and residual friction angel	Lab	A	N	N
Peak shear strength	Lab	A	N	N
Normal stiffness	Lab	A	N	N
Shear stiffness	Lab	A	N	N
Thermal Properties of Rocks				
Specific heat	Lab	A	N	N
Thermal conductivity	Lab	A	N	N
Coefficient of thermal expansion	Lab	A	N	N
Other Parameters				
In-situ stress	Site	—	N	—
Deformability modules	Site	A	N	A
Permeability test	Site	—	N	—
Piezometric level measurement	Site	N	N	—
Water flow measurement in tunnel	Site	—	—	N
Water flow measurement of springs	Site	—	A	N
Chemical analysis of water	Lab	A	N	A
Abrasivity*	Lab	A	N	—
Drillability*	Lab	—	N	—

NOTE — A : Advisable; N : Necessary; and (*) : for TBM Tunneling

ANNEX D

(*Foreword*)

COMMITTEE COMPOSITION

Geological Investigation and Subsurface Exploration Sectional Committee, WRD 05

Organization	*Representative(s)*
In Personal Capacity	Dr P. C. Nawani (***Chairman***)
AECS Engineering and Geotechnical Services Pvt Ltd, Noida	Shri Sanjeev Trehan Dr Tanu Raghuvanshi (*Alternate*)
AFCONS Infra Structure Limited, Mumbai	Dr Sunil Basarkar Shri P. S. Bansod (*Alternate*)
AIMIL Limited, New Delhi	Shri Heman Manchanda Shri Laxmidhar Mohapatra (*Alternate*)
Central Building Research Institute, Roorkee	Dr Koushik Pandit Dr P. K. S. Chavhan (*Alternate*)
Central Institute of Mining and Fuel Research, Roorkee	Dr J. K. Mohnot (*Alternate*) Dr Anil Swarup (*Alternate*)
Central Soil and Material Research Station, New Delhi	Shri N. P. Honkanadavar Shri Haridev (*Alternate*)
Central Water and Power Research Station, Pune	Dr G. Dhanunjaya Naidu Shri V. Chandrasekhar (*Alternate* I) Shri B. Suresh Kumar (*Alternate* II)
Central Water Commission, New Delhi	Director (FE & SA) Director Cmdd (E & NE) (*Alternate*)
Ferro Concrete Construction (I) Pvt Ltd, Indore	Dr Mahavir Bidasaria
Geological Survey of India	Dr Sandip Kumar Som Dr Saibal Ghosh (*Alternate*)
Gujarat Engineering Research Institute	Shri B. H. Chaudhari Shri Sanjay Shrivastav (*Alternate*)
Himachal Pradesh Power Corporation Limited, Shimla	Dr Poonam Binjolkar, Agm Shri Navneet Gupta, Dy Gm (*Alternate*)
Jammu & Kashmir State Power Development Corporation Limited	Shri Ravi Pandita, Chief Engineer
M/s Parsan Overseas Ltd	Shri Sanjay Rana Shri Ashutosh Kaushik (*Alternate*)
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National Institute of Rock Mechanics, Karnataka	Dr Ajay Kumar Naithani Dr Sandeep Nelliat (*Alternate*)
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National Thermal Power Corporation Limited, Noida	Shri Naveen Kumar Jain Shri Bhuvnesh Kumar(*Alternate*)
THDC India Limited, Rishikesh	Shri Ajay Kumar Shri Kailasah Chandra Uniyal (*Alternate*)
Uttarakhand Jal Vidyut Nigam Limited, Dehradun	Director (Projects) Dr Harish Bahuguna (*Alternate*)

Organization	*Representative(s)*
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